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Indian Standard

METHODS OF MEASUREMENT FOR CORES FOR INDUCTORS AND TRANSFORMERS FOR TELECOMMUNICATIONS

(First Revision)

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Indian Standard

METHODS OF MEASUREMENT FOR CORES FOR INDUCTORS AND TRANSFORMERS FOR TELECOMMUNICATIONS

(First Revision)

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Indian Standard
METHODS OF MEASUREMENT FOR CORES FOR INDUCTORS AND TRANSFORMERS FOR TELECOMMUNICATIONS
(First Revision)

0. FOREWORD

0.1 This Indian Standard (First Revision) was adopted by the Indian Standards Institution on 6 June 1980, after the draft finalized by the Magnetic Components and Ferrite Materials Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 This standard has been prepared to give guidance on measuring methods for magnetic and electric properties of magnetic cores of transformers and inductors.

0.3 Some of the methods described in this standard may also be suitable for magnetic cores used in other components.

0.4 This standard is limited to the general principles to be followed for various possible measuring methods and sets out the factors to be taken into account when deciding on the description of the test method to be included in a specification.

0.5 This standard has been subdivided into three sections as follows:

a) *Section* 1 — General, dealing with general stipulations and methods generally used in combination with measuring methods included in Sections 2 and 3;

b) *Section* 2 — Common measuring methods, dealing with those methods which form important parts of measurements of inductor and transformer cores; and

c) *Section* 3 — Specialized measuring methods, dealing with the methods intended for information purposes and only in special case, used for specification purposes.

0.6 In view of the technological advances, this standard which was first published in 1974, has been revised to modify certain test methods and to include other methods which were not covered by the earlier edition.

0.7 In preparation of this standard, assistance has been derived from IEC Publication 367-1 (1971) 'Cores for inductors and transformers for telecommunications: Part I Measuring methods', issued by International Electrotechnical Commission.

0.8 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS: 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard deals with the methods of measurement of magnetic and electric properties of magnetic cores, mainly made of ferromagnetic oxides or metallic powders, and used in inductors and transformers for telecommunication equipment and electronic devices employing similar techniques.

SECTION I GENERAL

2. UNITS AND LETTER SYMBOLS

2.1 All formulae in this standard use basic SI units. When multiples for submultiples are used, the appropriate power of 10 shall be used.

2.2 The following standard symbols are used in this standard:

t = time,
θ = temperature,
L = self inductance,
μ_0 = magnetic constant = $0 \cdot 4\pi \times 10^{-6}$ H/m,
μ_r = relative permeability†,
μ_i = initial permeability,
μ_e = effective permeability = $L\,C_1/\mu_0\,N^2$,
μ_{rev} = reversible permeability,
N = number of turns of measuring coil,
C_1 and C_2 = core factors as defined in IS : 7616-1974‡,
A_e = effective cross-sectional area, and
ω = angular frequency = $2\pi \times$ frequency of measuring current.

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*Rules for rounding off numerical values (*revised*).

†In the case of qualified versions of permeability, such as initial permeability μ_i, the relative quantity is meant, unless otherwise stated.

‡Guide for calculation of the effective parameters of magnetic piece parts.

3. ENVIRONMENTAL CONDITIONS

3.1 General — Normally, the cores are magnetically conditioned in accordance with **6**, not less than 24 hours before the measurements start.

During the whole procedure, the core shall be protected against mechanical shocks and vibrations and against magnetic disturbances. Condensation on measuring windings, which may occur at changing temperature, should be avoided.

3.2 Ambient Temperature — The assembled cores with measuring coil and clamping device shall be kept at ambient temperature of 25 ± 1°C for a sufficient time for the core to reach the state of thermal equilibrium. The temperature during the whole period of measurement shall not vary to such an extent as to have an appreciable effect on the results.

4. GENERAL PRECAUTIONS FOR METHODS INVOLVING PERMEABILITY MEASUREMENTS

4.1 Parameters Involved — The effective permeability of a core depends upon many factors, among which are the magnetic history, temperature, field strength, mechanical pressure, frequency of measuring current, core geometry, and geometry and position of the measuring coil. Various methods described in this standard single out one of these factors at a time, for example, time or temperature, and the precautions during these measurements should be directed towards eliminating the influence of all other factors. For example, a clamping device should be such that the pressure remains constant in time and with temperature, so that the measuring result is not influenced by changing pressure.

4.2 Relation to Practice — The measuring conditions shall be so chosen that the measured results are suitable for predicting the performance of the core under practical circumstances. This does not imply that all conditions have to correspond to those prevailing in practice.

4.3 Mounting of Cores Consisting of More Than One Part — For cores consisting of more than one part which assemble around the measuring coil, a clamping device shall be used throughout the measurements. This clamping device shall be able to:

a) distribute the clamping force uniformly over the contact surfaces, without introducing bending stresses in the core;
b) hold the core parts rigidly in position relative to each other;
c) give a transient overforce of about 10 percent when being closed, in order to breakdown fine irregularities between the cleaned contact surfaces;
d) exert a specified clamping force ±5 percent; and
e) keep the force constant within ±1 percent during the total period of the measurement.

NOTE — Keeping the force within ±1 percent is considered sufficient when the specified clamping force is chosen in the flat portion of the curve of permeability *versus* force. Otherwise closer tolerances may be required.

4.3.1 The mounting of such cores shall be done in accordance with the following instructions.

4.3.1.1 The contact surfaces shall be inspected for damage and cleanliness. Damaged cores shall not be used. When necessary, the contact surfaces shall be cleaned by non-abrasive means, for example, by rubbing gently on a dry wash leather.

4.3.1.2 Dust particles shall be blown off with clean dry compressed gas. The contact surfaces shall never be touched with bare fingers. The core part shall then be assembled around the measuring coil, the latter being locked in position with respect to the core by suitable means, for example, a foam washer. The core parts are centred and the core placed in the clamping device. The clamping force specified in the relevant specification shall then be applied. The clamped cores shall be kept under the specified environmental conditions (*see* **3**) for a time sufficient to allow any variation of effective permeability with time due to clamping to become negligible.

5. GENERAL PRECAUTIONS FOR LOSS MEASUREMENT AT LOW FLUX DENSITY

5.1 Contributory Losses — The loss measured on a core by means of a coil or other coupling device is due to a number of causes, some may be inherent in the core itself, some in the coupling device and some in the connection between the coupling device and the measuring instrument. In the case of measurement with a coil, the following loss components may be distinguished: core loss, dc coil loss, losses due to skin effect and proximity effect, dielectric loss in the coil, loss in connecting wires, and loss in any associated component, for example, resonator capacitor.

An attempt should be made to isolate the core loss from the total loss measured, either by correction or by choosing the condition so as to make the other contributory losses negligible. The dc coil loss and the loss in any associated component can be measured separately; the other contributory losses may be either calculated or determined experimentally.

The determination of the core loss does not present undue difficulties for ferrite cores without air gap or with a very small air gap (for example toroids and pot cores without intentional air gap) because with a suitably designed coil, the core loss then is appreciably higher than any other of the contributory losses.

This may not be the case for loss measurement on cores with gap and it may be impossible to obtain a sufficiently accurate measurement for the core loss alone. Two possible methods may be followed in that case, namely:

a) measure the loss factor before the air gap is ground and calculate the loss in the gapped core.

NOTE — It is not permissible to measure the loss factor on an ungapped core having a geometry different to that of the gapped core, for example, on a toroid of the same material, since the eddy current core loss strongly depends upon the core geometry.

b) make no attempt to separate core and coil loss but compare the combined loss of the core and the measuring coil with the results obtained from similar measurements of other cores using a coil of identical construction and having the same dc resistance.

The best policy is to obtain these measuring coils from the same source and from time to time compare the results of measurements with various coils on the same cores. Furthermore, the measuring results should be accompanied by the dc resistance value of the coil; when comparing the results obtained with different coils, the measurements shall be corrected to allow for the difference in coil resistance.

5.2 Mounting — Coupling between the stray field of the core and extraneous objects should be avoided. Connections between the measuring coil or other coupling device and the measuring instrument should be short, direct and so fixed that movement of the specimen cannot cause additional error.

Cores of more than one part which are assembled around the measuring coil shall in general be clamped as specified in **4.3** but the force is not so critical as in the case of inductance measurement.

Positioning of the measuring coil on the core shall be as specified in **7.2**.

6. MAGNETIC CONDITIONING

6.1 Object — To arrive at a well-defined and reproducible magnetic state of a core before the measurements are made.

6.2 Methods — There are two main methods, namely:

a) the electrical method in which the specimen is subjected to an alternating magnetic field of sufficient magnitude, of which the amplitude is gradually reduced to zero; and

b) the thermal method in which the specimen is taken above the Curie point.

6.3 Procedure of the Electrical Method — The initial peak of the field strength shall take the core well above the knee of the magnetization curve and during the reduction of amplitude there shall be two flux reversals in the core for each complete cycle.

There are two possibilities:

a) A decreasing alternating current is passed through the measuring coil on the specimen. The current decrease may be:

   1) linear, for example, by a potentiometer. The amplitude reduction shall then extend over not less than 50 cycles; or

2) exponential, for example, by a capacitor discharge. The ratio of two consecutive current peaks in the same direction shall be not less than 0·78 in that case.

The coil shall not be appreciably heated by the current during conditioning.

Further details on these methods are given in Appendices A and B.

b) The specimen is passed through the alternating field in the air gap of an electromagnet.

Further details on this method are given in Appendix C.

6.4 Procedure of the Thermal Method — The core shall be heated at a specified rate of temperature change and maintained for about 40 minutes at a temperature approximately 25°C in excess of the Curie point. Cooling shall also take place at a specified rate. For further details, see Appendix D.

7. INDUCTANCE MEASUREMENT

7.1 Object — To provide general instructions for the measurement of inductance of inductor and transformer cores without going into details of the method dependent upon the electrical instrument used.

7.1.1 Two measurement purposes should be distinguished:

a) to obtain a measurement of the absolute value of the inductance parameter of the core, and

b) to obtain a measurement of the dependence of the inductance parameter under certain conditions.

7.2 Means of Coupling — Normally, a measuring coil shall be used, but in principle any coaxial line, cavity or other suitable device providing the necessary interaction between the magnetic material and the electromagnetic signal, may also be used.

For measurement on toroids using coils, the turns of the measuring coil shall be distributed in such a way as to keep both the stray capacitance and the stray field as low as necessary for sufficiently accurate measurement.

For measurements on cores which assemble around a coil, the shape of the measuring coil shall correspond to that of the coils used for normal application of the core and its influence on the variation of the inductance to be measured shall be negligible.

Unless otherwise specified, the test coil, complete with coil former or encapsulation or both, shall be positioned coaxial to the limb which it embraces, and the side of the coil at which the start of the winding is located shall be lightly pressed into contact with the core at one end of this limb as follows:

a) For a symmetrical core, the coil assembly shall contact the core at either one end or the other; and

b) For a core that is symmetrical except for an air gap, the coil assembly shall make end contact with that half of the core which contains the least proportion of the air gap.

One of the coil faces shall be marked so as to define its orientation. The coil shall be kept in the defined position during the whole measurement in order to obtain the maximum reproducibility of the measurement.

Full details of the coil construction and position shall be given in the relevant Indian Standard. Guide for the design of inductance measurement coils for ferrite cores is given in Appendix E.

7.3 Absolute Measurement — Any suitable measuring apparatus may be used provided the accuracy is compatible with the specified tolerance, taking into account the reproducibility of other parts of the measuring method.

The frequency of the measuring current shall be low enough to avoid the influence of the capacitance of the measuring coil on the measuring result. Doubling the frequency shall not have an appreciable effect. For measurement of inductance corresponding to initial permeability, the flux density shall be vanishingly low, that is, of such level that doubling its value causes negligible change in the measured value. If necessary, the result may be corrected by linear extrapolation from measurements at low flux densities.

The frequency of the measuring current and the peak effective flux density shall be stated.

NOTE — The peak effective flux density $\hat{B}_e$ in a core is calculated from:

$$\hat{B}_e = \frac{U\sqrt{2}}{\omega NA_e}$$

where

U = rms value of the sinusoidal voltage applied to the coil.

7.4 Relative Measurement — The same details apply as for the absolute measurement, except that the absolute accuracy of the measuring instrument is not important as long as the relative inductance variation $\triangle L/L$ may be determined with the required accuracy over the part of the measuring range(s) used. A practical upper limit for the peak flux density in any core part is 0·25 mT and it shall be applied for not more than 1 minute for each measurement.

Where a frequency variation method is used, it shall be ensured that the frequencies are low enough to correspond to the flat portion of the permeability-frequency characteristic of the material, and that appreciable influence of the current distribution due to eddy currents in the measuring coil is avoided.

The (approximate) measuring frequency and the flux density shall be stated.

SECTION 2 COMMON MEASURING METHODS

8. DISACCOMMODATION

8.1 Object — To evaluate the changing with time of the permeability of a core.

NOTE 1 — Both components of the complex permeability will show disaccommodation but in this standard only the real component is considered.

NOTE 2 — Either the disaccommodation or the disaccommodation factor may be used to describe the variation with time (*see also* **8.6**).

8.2 Principle of the Method — The core is magnetically conditioned. The inductance or other quantity corresponding to initial permeability is measured at two specified times after magnetic conditioning. The disaccommodation factor (or the disaccommodation) is calculated from the difference in the measured values.

NOTE — The disaccommodation normally decreases with increasing flux density so that it is generally given for low values of flux density.

8.3 Specimens — Cores taken from normal production shall be used for the measurement.

When the complete core consists of more than one part, for example, a pot core, and the disaccommodation is to be measured with a normal winding, it is preferable that the only air gap in the flux path shall be the residual air gap at the contact surfaces. However, when there is a series of cores each with a different air gap cut into the flux path it may be permissible to make the measurement on cores with the smallest available air gap.

NOTE 1 — In some cases, such as pot cores with centre hole, the core parts may be wound as a toroid. The disaccommodation may be measured in that way after it has been established that the results are reasonably equal to or correlate with the results obtained with a normal winding and, moreover, the initial permeability along the toroidal flux path is not appreciably different from the initial permeability in the direction of the normal flux path. This method should be used with extreme caution. When a slotted pot core is toroidally wound, the outside walls make negligible contribution to the flux path.

NOTE 2 — For certain materials, the disaccommodation changes appreciably in the period immediately after firing. Where this is the case, the article sheet may specify that disaccommodation measurement for acceptance testing shall not be made within a stated period after manufacture and it shall also state from what instant this period shall be measured.

8.4 Timing Device — The inaccuracy of any time measurement shall not exceed 1 percent. In the case where the timing device is started by the magnetic conditioning device, this figure shall include the inaccuracy of both the starting technique and the timing device.

NOTE — In principle, for an electrical method the reference time shall be the moment when the field strength starts to decrease from the saturation value. For automatic conditioning systems, such as the capacitor discharge and power amplifier method, the whole magnetic conditioning process is so short as to fall within the tolerance of the time to the first measurement.

8.5 Measuring Procedure

8.5.1 The core is assembled with a measuring coil in accordance with **4.3**.

8.5.2 The core shall be subjected to magnetic conditioning by one of the methods given in **6**. The method used shall be stated together with the main characteristics of the conditioning device. In all cases, the instrument shall clearly and reproducibly indicate the moment of the magnetic conditioning since this forms the starting point of the measurement and strongly influences the accuracy of disaccommodation measurement.

8.5.3 Two readings are taken in accordance with **7.4**:

a) In the electrical method, the first one 10 minutes and the second one 100 minutes after magnetic conditioning; and

b) In the thermal method, the first one 24 hours and the second one 48 hours after measurement reference time t_0 which is defined as the moment when, during the cooling period, the temperature reaches a point 10°C above the measurement temperature.

Other times may be used, but preferably the whole procedure shall not take more than 24 hours for the electrical method. The measuring procedure and environmental conditions shall be identical at the two measurements.

8.6 Calculation — The disaccommodation D between t_1 and t_2 is calculated from the difference of the two readings relative to the first reading. In the case of inductance measurement, it is calculated from:

$$D = \frac{L_1 - L_2}{L_1}$$

The disaccommodation factor D_F may be calculated from:

$$D_F = \frac{\mu_0 N^2 (L_1 - L_2)}{C_1 L_1^2 \log_{10}\left(\frac{t_2}{t_1}\right)}$$

where

L_1 = self-inductance measured at t_1 minutes after magnetic conditioning, and

L_2 = self-inductance measured at t_2 minutes after magnetic conditioning.

NOTE — The disaccommodation has been found to be approximately proportional to the logarithm of time, and for this reason the disaccommodation factor is normally used to express the variability with time. Within the limits of the approximation, the disaccommodation of a core with air gap may be derivd from the disaccommodation factor of the material.

$$D = \mu_e D_F \log_{10} \left(\frac{t_2}{t_1}\right)$$

Due to limitations of the manufacturing process, the properties of cores with different geometric shapes made of the same material may differ.

9. VARIATION OF PERMEABILITY WITH TEMPERATURE

9.1 Object — To evaluate the change with temperature of the permeability of a core.

NOTE 1 — Both components of the complex permeability shall show temperature variability but in this standard only the real component is considered.

NOTE 2 — When permeability and temperature of a core are simultaneously recorded, a large band of measuring points is obtained. The variation of permeability with temperature may be characterized with absolute accuracy in a single figure only for an infinitely small temperature range.

The concept of a temperature coefficient or a temperature factor applying over a finite temperature range is still desirable. A practical value permitting calculations to be made, with adequate accuracy may be obtained by properly choosing the measuring conditions and temperature limits under which the temperature coefficient or factor applies.

9.2 Methods — The required accuracy of the method has a bearing on its simplicity and duration and for this reason three different measurement methods are distinguished.

Method A — The assembled core with measuring coil is taken through a temperature cycle at a very low rate of variation of the temperature. After one or more stabilizing cycles, both the temperature and the inductance are continuously recorded.

Method B — The assembled core with measuring coil is taken through a temperature cycle at a moderate rate of variation of the temperature. After one or more stabilizing cycles, the cycle is interrupted at certain temperatures. During each interruption, the temperature is kept constant for a sufficient time to allow the core to attain temperature equilibrium before the measurement is made.

Method C — The assembled core with measuring coil is taken through a temperature cycle at a moderate rate of variation of the temperature. After one or more stabilizing cycles, the cycle is interrupted at a certain temperatures. During each interruption, the temperature is kept constant. After the core has reached thermal equilibrium, it is magnetically conditioned and the measurement is made after a clearly defined time.

NOTE — Since the disaccommodation varies with temperature, Method C may give results which differ appreciably from those obtained with Method A or Method B, but since it is more rapid, it is useful, provided the results reliably correlate with Method A or Method B.

9.3 Specimens — Cores taken from normal production shall be used for the measurement.

When the complete core consists of more than one part, for example, a pot core, and the temperature variation is to be measured according to Method C with a normal winding, it is preferable that the only air gap in the flux path shall be the residual air gap due to the contact surfaces.

NOTE — In some cases, such as pot cores with centre hole, the core parts may be wound as a toroid. The temperature variation may be measured in that way after it has been established that the results are reasonably equal to or correlate with the results obtained with a normal winding. This method should be used with extreme caution. When a slotted pot core is toroidally wound, the outside walls make negligible contribution to the flux path.

9.4 Temperature Cycling Device — It shall comply with the following requirements:

a) *For Method A* — A temperature controlled chamber shall be used in which the temperature change with time is practically linear and may be kept at 0·2°C/min.

b) *For Methods B and C* — The chamber used for this test shall be capable of maintaining, in any region where the components are placed, the specified temperature with a tolerance of ±1°C, and the temperature shall be kept constant with time within ±0·1°C. The temperature in the chamber shall be so controlled that the cores are not subjected to any temperature ripple and overshoot exceeding this limit of ±0·1°C.

c) *Thermometers* — The thermometers shall have such sensitivity and accuracy that it is possible,

   1) to check that the temperature is constant within ±1°C, and

   2) to measure within ±1 percent the total temperature difference over which the temperature dependence is to be measured.

9.5 Timing Device (for Method C Only) — The inaccuracy of any time measurement shall not exceed 1 percent. In the case where the timing device is started by the magnetic conditioning device, this figure shall include the inaccuracy of both the starting technique and the timing device.

NOTE — In principle, the reference time shall be the moment when the field strength starts to decrease from the saturation value. For automatic conditioning systems, such as the capacitor discharge and power amplifier method, the whole magnetic conditioning process is so short as to fall within the tolerance of the time of the measurement.

9.6 Measuring Procedure

9.6.1 The core is assembled with a measuring coil in accordance with **4.3**. Additional requirements for the temperature dependence of the measuring coil are under consideration. The tolerance of ±1 percent on the clamping force includes any force variation due to temperature change.

9.6.2 The core shall be subjected to a number of stabilizing cycles and one measuring cycle. Usually two stabilizing cycles are sufficient. They are identical to the measuring cycle described below as to temperature range and specified rate of temperature change, but the periods at constant temperature specific to the measuring cycles may be left out:

Method A — The assembled core is placed in the chamber and after the specified number of stabilizing cycles, it is brought to the highest measuring temperature specified, then to the lowest measuring temperature specified and finally back to the temperature at which the cycle was started. The rate of temperature change shall be approximately 0·2°C/min, and constant throughout the cycle. Temperature and inductance shall be recorded simultaneously during the measuring cycle at time intervals not exceeding 1 minute. The time of starting the measurement shall also be recorded.

Method B — The assembled core is placed in the chamber and after the specified number of stabilizing cycles, it is kept at the temperature specified for the initial measurement for 30 minutes after temperature equilibrium has been attained, after which a measurement is made (reference value). The temperature is varied at a maximum rate of 1°C/min to the lowest specified measuring temperature and kept constant as specified above, after which a measurement is made. The temperature is then raised at a maximum rate of 1°C/min to the next higher specified measuring temperature and kept constant as specified, after which another measurement is made.

This procedure is continued until the highest specified measuring temperature, after which the temperature is lowered at a maximum rate of 1°C/min to the temperature for initial measurement, where the final measurement is made after a period of constant temperature as specified above.

Method C — The assembled core is placed in the chamber and brought to the lowest of the specified measuring temperatures at a rate sufficiently low as not to create an excessive temperature gradient in the material (normally, 1°C/min will be a suitable value). The temperature is maintained for a sufficient time to allow the core assembly to reach thermal equilibrium with the atmosphere in the chamber. The core is then magnetically conditioned according to **6.3**(a) with a decreasing alternating current through the measuring coil, and the inductance of the measuring coil is measured 10 minutes after conditioning The temperature is then raised to the next higher specified measuring temperature at the rate specified above. The maintaining of temperature, magnetic conditioning and inductance measurement are repeated at that temperature. This procedure is continued until the highest measuring temperature specified (*see* Note under **9.2**).

9.6.3 The inductance readings are taken in accordance with **7.4**. The measuring procedure and environmental conditions shall be identical throughout the measurement of one cycle, except for the temperature.

9.7 Calculation — The temperature coefficient, α_μ, for each measurement is calculated from the relative difference between that measured value and the reference value divided by the corresponding temperature difference. In the case of inductance measurements it is calculated from:

$$\alpha_\mu = \frac{L_\theta - L_{ref}}{L_{ref}\,(\theta - \theta_{ref})}$$

where

L_θ = self-inductance of measuring coil at temperature θ, and

L_{ref} = self-inductance of measuring coil at reference temperature θ_{ref} (preferably 25°C).

For Method A, the values are read from the recorded curve.

NOTE 1 — The temperature coefficient is commonly used to calculate the limits of change of permeability of a core within a given temperature range. It may only be used to describe the behaviour within that temperature range, when the limits of linearity of the permeability *versus* temperature characteristic of the core are taken into account.

It should be noted that, because of the non-linearity of this characteristic, the temperature coefficient may be different for different temperature ranges. Further, the deviation from the straight line is not always reduced when a smaller temperature range is chosen.

Some methods of expressing temperature dependence are given in Appendix F.

NOTE 2 — For series of cores with different air gaps cut into the flux path (such as pot cores), the temperature coefficient α_μ may be calculated from the temperature factor α_F of the core in which the only air gaps in the flux path are the residual air gaps due to the contact surfaces. The required relation is:

$$\alpha_\mu = \frac{\alpha_F\,\mu_e}{1 - \alpha_F\,\mu_e\,(\theta - \theta_{ref})} \approx \alpha_F\,\mu_e$$

where

α_F = temperature factor of the core without air gap, over the range θ_{ref} to θ, calculated from measurements on that core according to:

$$\alpha_F = \frac{\mu_0\,N^2}{C_1} \times \frac{L_\theta - L_{ref}}{L_\theta\,L_{ref}\,(\theta - \theta_{ref})}\ ;\ \text{and}$$

μ_e = effective permeability of the core with air gap at reference temperature θ_{ref}.

The approximate formula holds true when the total variation of permeability of the core with air gap over the temperature range is sufficiently small. It may also be written:

$$\alpha_\mu = \frac{C_1}{\mu_0}\,\alpha_F\,A_L$$

where

A_L = inductance factor of the core with air gap.

NOTE 3 — The temperature coefficient of an inductor may be totally different from that of the core, since various influences on the variability are introduced, for example, by the clamping, by the copper winding.

10. RANGE OF INDUCTANCE ADJUSTMENTS

10.1 Object — To provide a method for the measurement of the range of adjustment of the inductance of magnetic cores having a separate adjusting device.

10.2 Terminology — For the purpose of this method, the following definitions shall apply.

10.2.1 *Adjusting Device* — A device providing adjustment of the inductance of an inductor or tuned transformer, after its complete assembly, by changing the reluctance of the core.

10.2.2 *Fixed Part (of an Adjusting Device)* — The part of an adjusting device which is mechanically attached to the core by such means as cement.

10.2.3 *Adjuster* — The part of an adjusting device which may assume different positions relative to the air gap of the core.

10.2.4 *Adjustment Range* — The difference in inductance of an inductor when the adjuster is placed in the maximum and minimum position respectively, expressed as a percentage of the inductance of that inductor without adjuster.

10.2.5 *Upper (Lower) Limit of the Adjustment Range* — The difference in inductance of an inductor when the adjuster is placed in the maximum (minimum) position and when the adjuster is removed, expressed as a percentage of that latter inductance:

$$a = \frac{L_{\min} - L_0}{L_0} \times 100 \text{ percent}$$

$$b = \frac{L_{\max} - L_0}{L_0} \times 100 \text{ percent}$$

where

a = lower limit with inductance $L_{\min}$,

b = upper limit with inductance $L_{\max}$, and

L_0 = inductance when adjuster is removed.

10.2.6 *Maximum (Minimum) Position of the Adjuster* — Position defined by mechanical requirements or other conditions and which corresponds to the upper (lower) limit of the adjustment range.

10.2.7 *Screw-Type Adjusting Device* — Adjusting device in which the adjuster screws into or onto the fixed part (nut or stud).

10.3 Principle of the Measurement — The inductance of the core without adjuster is measured. The adjuster is then placed in the minimum position and the inductance measured at small steps of the adjuster until the maximum position has been reached. The relative change of inductance is plotted against the adjuster displacement.

10.4 Specimens — Adjusting devices taken from normal production shall be used for the measurement in combination with appropriate cores.

10.5 Measuring Procedure

10.5.1 If the fixed part has not been attached to one of the core parts by the manufacturer, this shall be done according to the manufacturer's instructions.

10.5.2 The core is assembled with the measuring coil in accordance with **4.3**.

10.5.3 The adjuster shall be introduced into the core and moved twice through the complete adjustment range and back. The adjuster is then removed from the core.

NOTE — Too many movements through the adjustment range may result in deterioration of the stability and should therefore be avoided.

10.5.4 The inductance is measured in accordance with **7**.

10.5.5 The adjuster is introduced into the core and placed in the minimum position. The inductance is measured in accordance with **7**.

10.5.6 The adjuster is then successively displaced over a small distance and each time the inductance is measured till the maximum position is reached. The steps shall be small enough to detect irregularities in the adjustment characteristic (*see* **10.6**), for example, for screw-type adjusters, quarter turn.

10.6 Calculation — The inductance change relative to the inductance measured with the adjuster removed shall be plotted against the mechanical position (displacement) of the adjuster. For screw-type adjusters, the displacement shall be given in number of turns and for push-types it shall be given in millimetres.

The maximum and minimum slope (*see* Fig. 1) of the curve shall be noted as required. The slope is defined as the differential for a small displacement made during the measurement.

11. LOSS AT LOW FLUX DENSITY

11.1 Object — To provide general instructions for the measurement of loss, both in gapped and ungapped cores, and to establish reference methods for the calibration of loss measuring instruments.

11.2 Specimens — Cores taken from current production shall be used for the measurement. For cores which are used with an air gap in the flux path, such as pot cores for inductors, the loss may be measured before grinding that air gap (*see also* **11.4**).

11.3 Means of Coupling — Normally, a measuring coil is used, but in principle, any coaxial line, cavity, or other suitable device, providing the necessary interaction between the magnetic material and the electromagnetic signal, may also be used.

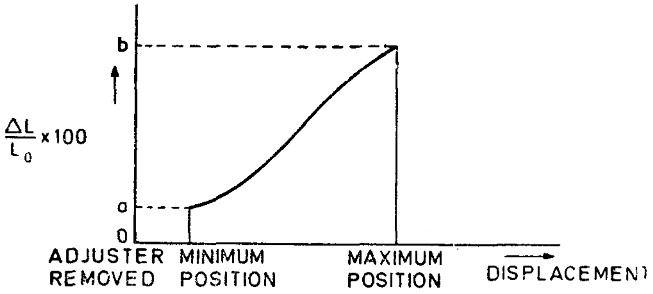

FIG. 1 CURVE SHOWING PERCENT INDUCTANCE CHANGE RELATIVE TO INDUCTANCE MEASURED AGAINST DISPLACEMENT OF ADJUSTER

11.3.1 Measuring coils sensitive to the influence of moisture should be stored under dry conditions and measurements should preferably take place under standard atmospheric conditions for referee tests.

11.3.2 Full details of the construction of the coil or other device shall be given in the relevant specification. The conditions shall be based on the following considerations:

a) Coils for cores consisting of more than one part shall, when possible, be designed to have the optimum frequency for the core-coil combination well below the measuring frequency, so that the coil loss can be neglected. Where the above is not possible, an attempt should be made to keep the additional winding loss and the dielectric loss in the coil insulation as low as possible by using standard wire, a low number of turns or subdivided coils or both, so that measuring results need only be corrected for the dc resistance loss of the coil.

   Where correction for coil loss would result in an unacceptable inaccuracy, standard coils shall be used and the combined loss of core and coil shall be specified [*see* **5.1**(b)]. For measurement on high-Q cores, such as gapped cores, the standard coils should be exchanged between parties making measurements on the same cores.

b) Coils wound on toroids shall be evenly distributed. It is preferable that insulated solid copper wire be used and that it completely covers the toroid.

NOTE — Solid copper wire is recommended because of the risk of breaking of wire strands when winding a toroid. For measurements at high frequencies, however, stranded wire may be necessary.

c) In all cases, the self capacitance of the coil on the core should preferably be less than 2 percent of the resonating capacitance to avoid both excessive dielectric loss and correction of the measured inductance (where measurement of the latter is required).

11.4 Residual Plus Eddy Current Loss — Any suitable measuring apparatus may be used provided the accuracy is compatible with the specified loss limit. It shall allow the flux density in the core to be adjusted to the specified value. Unless otherwise specified, this value is equal to or lower than the value used for the measurement of inductance on the same core according to **7**. The value of flux density during measurement shall be stated. The measuring frequency or frequencies shall be specified in the relevant specification.

11.4.1 It may be required to correct for coil loss or for loss in the tuning capacitor or both. The following method is recommended for the correction for coil losses:

> Measure the series resistance and inductance of the coil with core and subtract the equivalent resistance of the coil, that is, the measured dc resistance of the coil increased by the equivalence of the estimated additional coil losses at the measuring frequency (*see* **11.3**). Finally make any required transformation to parallel resistance, quality factor or other quantity in which the core loss has to be expressed.

Finally, make any required transformation to parallel resistance, quality factor or other quantity in which the core loss has to be expressed.

When the loss factor is measured before the grinding of the air gap, the loss in a core with air gap can be calculated from:

$$(\tan \delta)_e = \left(\frac{\tan \delta}{\mu_1}\right) \times \mu_e$$

where

$(\tan \delta)_e$ = tangent of loss angle in the gapped core with effective permeability μ_e,

$\left(\frac{\tan \delta}{\mu_1}\right)$ = loss factor measured on the core (or on a core of the same lot or series) before the grinding of the air gap, and

μ_e = effective permeability of the gapped core.

11.5 Hysteresis Loss — Any suitable measuring apparatus may be used which allows the variation of the core loss with amplitude to be determined with the required accuracy.

11.5.1 The value of the hysteresis loss shall be derived from loss measurements at two values of the peak voltage specified in the relevant specification, which shall be so chosen that the peak effective flux density in the core is smaller than 5 mT. When necessary, the inductance of the measuring coil with core shall be measured at the lower voltage value.

11.5.2 The measuring frequency or frequencies shall be as specified in the relevant specification.

11.5.3 The hysteresis loss shall be calculated on the basis of proportionality to the ratio of measured loss difference to applied peak voltage difference. Correction for coil loss is not normally required.

Example:

a) For individual cores:

$$\tan \delta_h = \frac{\hat{U} \triangle R_s}{\omega L_s \triangle \hat{U}}$$

where

$\tan \delta_h$ = tangent of the loss angle due to hysteresis loss,
$\hat{U}$ = higher applied measuring peak voltage,
$\triangle R_s$ = measured difference in series resistances,
L_s = series inductance of coil on core at lower applied measuring voltage,
$\triangle \hat{U}$ = difference in applied measuring peak voltages, and
ω = 2 π × measuring frequency.

b) For materials and for cores which may have different air gaps:

$$\eta_B = \frac{\omega^2 N^3 \mu_o}{C_2} \times \frac{\triangle G_p}{\triangle \hat{U}} T^{-1}$$

where

η_B = hysteresis material coefficient,
ω = 2 π × measuring frequency,
$\triangle G_p$ = measured difference in parallel conductance, and
$\triangle \hat{U}$ = difference in applied measuring peak voltages (*see also* **2** for explanation of symbols).

NOTE — If it is assumed that η_B as a material constant is independent of μ_e and $\hat{B}$, then it follows that $\tan \delta_h$ for a core with given μ_e is proportional to $\hat{B}$.

11.6 Reference Methods — For loss measurement on gapped cores with a high quality factor and on ungapped or toroidal cores with a moderate quality factor, the measuring apparatus shall be calibrated by means of a reference method. Two reference methods are recommended, namely, a damped oscillation method (*see* Appendix G) and a transmission loss method (*see* Appendix H).

SECTION 3 SPECIALIZED MEASURING METHODS

12. THIRD HARMONIC DISTORTION

12.1 Object — To determine the third harmonic distortion generated in a core.

12.2 Terminology — For the purpose of this method, the third harmonic material constant (δ_B) is defined by:

$$\delta_B = \frac{E_3}{\mu_e \hat{B} U_1}$$

where

E_3 = electromotive force of third harmonic frequency generated by the core,

$\hat{B}$ = peak value of flux density corresponding to U_1, and

U_1 = applied (rms) voltage of fundamental frequency.

12.3 Principle of the Measurement — Two principal methods are possible, namely:

a) *Low Impedance Method* — An oscillator supplies current at fundamental frequency to the measuring coil on the core; a filter blocks any third harmonic current generated in the oscillator. The circuit in series with the measuring coil has an impedance, at the third harmonic frequency, which is much smaller than the reactance of the measuring coil at the same frequency.

   The third harmonic voltage is measured across a known resistance in the circuit (which may be the total resistance in series with the coil). The material constant δ_B is calculated from this measured value, the fundamental voltage applied to the measuring coil, and circuit and coil parameters.

b) *High Impedance Method* — An oscillator supplies current at fundamental frequency to the measuring coil on the core; a filter blocks any third harmonic current generated in the oscillator. The circuit in series with the measuring coil has an impedance, at third harmonic frequency, which is much larger than the reactance of the measuring coil at the same frequency.

   The third harmonic electromotive force developed in the coil is measured. The material constant δ_B is calculated from this measured value, the fundamental voltage applied to the measuring coil, the circuit and coil parameters.

   NOTE — When the impedance in series with the measuring coil is sufficiently high, the electromotive force may be measured as the voltage developed across the coil. When this is not the case, an injection method should be used (*see* **12.6.4**).

12.4 Specimens — Cores taken from normal production shall be used for the measurement.

12.5 Measuring Instruments — Any suitable commercially available third harmonic measuring instrument or an arrangement of measuring equipment having suitable characteristics may be used. The following requirements shall be met:

a) The accuracy of the measured voltage shall be better than 5 percent; and

b) Circuit components in the neighbourhood of the specimen shall be virtually free from non-liner distortion. With a liner component in the place of the specimen (for example, an air cored coil), the third harmonic shall be at least 120 dB below the fundamental.

For checking the measuring systems a suitable device with known non-linearity should be provided, for example, a zener diode resistor network.

NOTE — Requirements for the filters follow from the above requirements and depend upon the chosen measuring circuit. Some details are given in Appendix J.

12.6 Measuring Procedure

12.6.1 The core is assembled with a measuring coil in accordance with **4.3**.

12.6.2 When the high impedance method is used, the inductance of the coil is measured in accordance with **7** to obtain the effective permeability of the core.

12.6.3 *Direct Measurement* — The coil is inserted in the measuring circuit. The measuring circuit is adjusted to the specified frequency and the third harmonic voltage is measured in accordance with the procedure appropriate to that circuit.

12.6.4 *Injection Method* — When using the high impedance method, if the impedance in series with the measuring coil is not sufficiently high relative to that of the coil, the measuring coil is inserted in the circuit in series with a resistor of known small value (for example, 1Ω).

The measuring circuit is adjusted in accordance with the procedure appropriate to that circuit. The voltage of the specified fundamental frequency is applied to the circuit and the deflection of the third harmonic voltmeter noted. The fundamental voltage is then removed and a third harmonic voltage is applied across the resistor in series with the coil. When the same deflection of the third harmonic voltmeter in the circuit is obtained the voltage applied across the resistor is assumed equal to the electromotive force. This applied voltage shall then be measured.

12.7 Calculation — The third harmonic material constant δ_B is calculated from:

a) When the low impedance method is used and the third harmonic voltage is measured:

$$\delta_B = \frac{3\omega_1^2 \mu_0 N^3}{C_2 R\sqrt{2}} \quad \frac{U_3}{U_1^2}$$

where

ω_1 = fundamental angular frequency,

U_3 = third harmonic voltage measured across a known resistance R in the circuit (which may be the total circuit resistance in series with the coil), and

U_1 = fundamental voltage applied to the measuring coil.

b) When the high impedance method is used:

$$\delta_B = \frac{N\omega_1 A_e}{\mu_e \sqrt{2}} \; \frac{E_3}{U_1^2}$$

where

A_e = effective cross-sectional area of the core (*see* IS: 7616-1974*), and

E_3 = electromotive force of third harmonic frequency generated by the core.

NOTE — At the lower end of the frequency range of a material, the third harmonic material constant is approximately related to the hysteresis material constant according to:

$$\eta_B \approx \frac{5}{3}\delta$$

The above expression is exact only in cases where the Rayleigh-Jordan relationship is valid.

13. MAGNETIC SHOCK SENSITIVITY

13.1 Object — To provide a method for the determination of the change in effective permeability of a core caused by a single impulse of magnetization.

13.2 Terminology — For the purpose of this standard, magnetic shock sensitivity K_s of a core is defined as the ratio of the difference between the effective permeability after magnetic conditioning (μ_{ec}) and the effective permeability after application of an impulse of magnetization (μ_{em}), to the first mentioned effective permeability:

$$K_s = \frac{\mu_{em} - \mu_{ec}}{\mu_{ec}}$$

13.3 Principle of the Measurement — The core is magnetically conditioned and the inductance corresponding to initial permeability is measured. A static magnetic field saturating the material is applied for a short time (magnetic shock), after which the inductance is again measured. The magnetic shock sensitivity is calculated from the difference in measured value.

13.4 Specimens — Cores taken from normal production shall be used for the measurement. When it is desired to judge the magnetic shock sensitivity of a material, toroids may be used as specimens.

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*Guide for calculation of the effective parameters of magnetic piece parts.

13.5 Pulse Generator — The pulse generator shall be capable of maintaining a direct current for approximately 2 seconds and then reducing the current to zero over a period of approximately 2 seconds in such a way that oscillations are avoided.

NOTE — For the special case of loading coils, these times defining the current pulse shall each be approximately 5 seconds.

13.6 Timing Device — The inaccuracy of any elapsed time measurement shall not exceed 1 percent.

NOTE — In principle, the reference time shall be the moment when the field strength starts to decrease from the saturation value. Both the magnetic conditioning and the impulse magnetization are short compared with the time tolerance of ±10 seconds specified in **13.7**, except in the case of loading coils.

13.7 Measuring Procedure

13.7.1 The core is assembled with the measuring coil in accordance with **4.3**.

In the case of a toroidal winding, the turns shall be distributed in such a way as to keep both the stray capacitance and the stray field as low as possible.

The coil shall not be unduly heated by the current pulse.

13.7.2 The core shall be subjected to magnetic conditioning by one of the possibilities according to **6.3**(a) with a decreasing alternating current through the measuring coil. The method used shall be stated together with the main characteristics of the conditioning device.

13.7.3 The inductance is measured 300±10 seconds after magnetic conditioning in accordance with **7**. During measurement, the peak value of flux density in any core part shall not exceed 0·25 *mT* and it shall be applied for not more than 1 minute. The measuring frequency shall be stated.

13.7.4 Immediately after the inductance measurement of **13.7.3**, a direct current pulse saturating the core is applied to the measuring coil (*see* **13.5**).

NOTE — In some cases it may not be possible to achieve saturation. In practice the number of turns of the coil and the current will be specified.

13.7.5 The inductance is again measured 300±10 seconds after the end of the direct current pulse under conditions identical to those during the measurement of **13.7.3**.

13.8 Calculation — The magnetic shock sensitivity K_s is calculated from:

$$K_s = \frac{(L_m - L_c)}{L_c}$$

where

L_m = self-inductance measured in **13.7.5**, and

L_c = self-inductance measured in **13.7.3**.

NOTE — For cores with air gap, it is possible to estimate the behaviour of one core from measurement on another of the same size, shape and material but with different air gap, when the effective permeabilities of both cores lie within the range of 10 to 50 percent of the initial permeability of the material:

$$K_{s2} = \frac{\mu_{e2}}{\mu_{e1}} K_{s1}$$

where

K_{s2} = derived magnetic shock sensitivity for a core of the same size, shape and material with effective permeability μ_{e2}, and

K_{s1} = magnetic shock sensitivity measured on the core with effective permeability μ_{e1}.

It is, however, impossible to predict the behaviour of a core with air gap from measurement of the magnetic shock sensitivity made on a core without air gap. This is due to the demagnetization effect of the air gap.

14. CONTRIBUTION OF THE ADJUSTING DEVICE TO THE CORE INSTABILITY

14.1 Object — To establish the relative merits of different types of adjusting devices with regard to their stability when used in magnetic cores.

NOTE 1 — Reversible changes, such as caused by temperature variation, are not within the scope of this method.

NOTE 2 — The instability of a tuned assembly is generally attributed to small displacements due to mechanical stress relaxations. Under normal conditions, this relaxation may go on for a long time, for example, several years.

14.2 Terminology — The definitions given in **10.2** apply to this method together with the following definitions.

14.2.1 *Core (Assembly)* — Magnetic core assembled around a measuring winding and capable of being used with an adjusting device, but excluding the actual adjuster. Unless otherwise stated, the fixed part of the adjusting device is attached to that core.

14.2.2 *Tuned Assembly* — Core assembly in which the adjuster has been introduced. It does not imply that the assembly has been tuned to a specified inductance.

14.3 Principle of the Method — A core assembly is stabilized by applying an appropriate number of thermal cycles. When the residual instability of the inductance measured on the core assembly is sufficiently low, the adjuster is introduced into the core and the instability of the inductance of the tuned assembly measured for a given number of cycles.

NOTE — This method, when applied separately, will assess the instability of the adjusting device as caused by normal ageing. It is possible to combine this method with environmental tests of IS : 589-1961*, such as bump, vibration and humidity.

14.4 Specimens — Cores and adjusting devices taken from normal production shall be used for the measurement.

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*Basic climatic and mechanical durability tests for components for electronic and electrical equipment (*revised*).

14.4.1 Where the adjusting device is completely mounted in the core by the inductor manufacturer, one set of stabilized cores may be used to check successive batches of adjusters.

14.4.2 Where the fixed part of the adjusting device is mounted in the core by the core manufacturer, cores should be stabilized from successive core batches. Where the use of the adjusting device is not limited to cores of one manufacturer, the core dimensions warranting adequate fitting (such as hole diameter limits) shall be indicated, or agreement shall be reached between the manufacturers involved.

NOTE — The contribution of the adjusting device to the instability depends on several factors external to the adjuster itself, such as size of core (one adjuster may be used for several core sizes), geometry of core, material permeability, size of air gap, and adjustment range as affected by relation to core geometry. For meaningful comparisons it is therefore necessary to standardize the external factors.

14.5 Conditioning Chamber — The chamber shall be capable of performing the specified temperature cycle within 4 hours. It shall meet the general requirements for the dry heat chamber specified in **7.2.1** of IS : 589-1961*.

14.6 Measuring Procedures

14.6.1 If the fixed part has been attached to one of the core parts by the manufacturer, this shall be done according to the manufacturer's instructions.

14.6.2 The core is assembled with the measuring coil in accordance with **4.3**, the half cores being aligned in accordance with the manufacturer's instructions. The easy introduction of the adjuster shall be checked and it shall also be verified whether the tuned assembly meets the relevant requirements of its specification. For example, for screw type adjusters in pot cores the eccentricity of the fixed part shall be checked and cores not complying with the specification requirement shall not be used.

14.6.3 The core is then placed in the conditioning chamber on a non-conducting shelf in a position permitting insertion of the adjuster without physical disturbance of the core in relation to its environment. Neighbouring cores shall not touch each other and connecting leads should be rigid.

14.6.4 The core assembly shall be subjected to a series of identical temperature cycles as shown in Fig. 2.

The lower temperature of the cycle shall be +30°C and the upper +70°C, throughout the test these shall be maintained within a tolerance of ±2°C except when the inductance is being measured (*see* **14.6.5**).

The cycle time t shall be between 4 and 10 hours depending on the core sizes but it may also be chosen at 24 hours or another convenient value in the case of manual operation. The constant temperature regions t_1 shall be equal in duration and not less than $1\frac{1}{2}$ hours. The points M indicate

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*Basic climatic and mechanical durability tests for components for electronic and electrical equipment (*revised*).

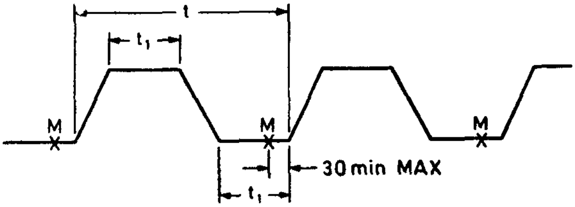

FIG. 2 TEMPERATURE CYCLES

the time of inductance measurement; it shall not be more than 30 minutes before the time at which the temperature starts to rise.

The time intervals of the cycle having been chosen, they shall be maintained within a tolerance of ±0·5 percent of that interval throughout the whole sequence.

NOTE — In special circumstances it may be required that the lower temperature should be below 30°C. In that case a standard temperature shall be chosen in accordance with **4** of IS : 589 - 1961*.

14.6.5 The inductance is measured in accordance with **7.4**, preferably with a 'free-running oscillator' method. In addition, the peak value of the flux density in any part of the core shall not exceed 2·5 *mT* and it shall be maintained at the chosen value within ±0·005 *mT* for all measurements. The measuring current shall not be applied for more than 1 minute for each measurement. The difference in core temperature at any two measurements shall not exceed 0·4°C.

The method used and the main characteristics of the measuring apparatus should be stated.

NOTE 1 — No magnetic conditioning shall be applied to the core at any time during the measuring sequence.

NOTE 2 — The tolerance on the flux density has been chosen to ensure that the resulting relative change of inductance will be less than 50×10^{-6}.

14.6.6 The series of cycles shall continue until any two of three successive measurements of the fractional change of inductance performed at the measuring times M do not differ by more than 150×10^{-6}.

NOTE — If it is subsequently found that the results obtained according to **14.7** are not substantially greater than this figure, the test may be repeated using a suitably lower figure.

14.6.7 The adjuster shall then be carefully introduced into the core, moved twice through the total adjustment range and adjusted to the nominal electrical mid-range position without disturbing the core, coil, leads, etc. This operation shall be performed within 30 minutes of the core attaining the temperature of 30°C.

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*Basic climatic and mechanical durability tests for components for electronic and electrical equipment (*revised*).

14.6.8 The cycling shall continue for at least six cycles without any irregularity being introduced by the operation of inserting the adjuster and the inductance measurements being made as specified in **14.6.5**.

14.6.9 When a sufficient number of cycles has been completed the adjuster shall be removed with the same care exercised during insertion, within 30 minutes of the core attaining the temperature of 30°C, after which the core assembly shall be subjected to an additional temperature cycle. The value of the inductance obtained at the next measurement point *M* shall not differ from the average of the last three measurements referred to in **14.6.6** by more than 150×10^{-6}. If the difference exceeds this figure, the test results on the adjuster shall be disregarded and the procedure, including the assessment of core stability, shall be repeated.

14.7 Calculation — The relative change of inductance of the tuned assembly as compared to the first inductance measurement of **14.6.8** shall be plotted on a graph as shown in Fig. 3.

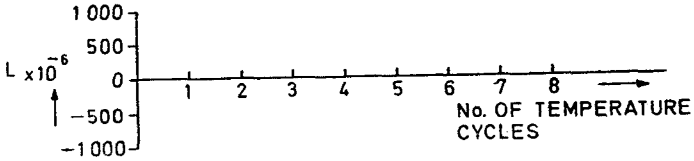

Fig. 3 Graph to Show Relative Change of Inductance

To allow meaningful comparisons, a statement defining the test conditions of the adjusting device should accompany the measuring results (type of core, air gap, etc, *see* Note under **14.4.2**). The temperature coefficient and disaccommodation of the core should also be indicated to draw attention to possible sources of measurement error.

15. INFLUENCE OF A STATIC MAGNETIC FIELD

15.1 The details of method of measurement of influence of a static magnetic field are given in Appendix K.

APPENDIX A

(*Clause* 6.3)

APPARATUS FOR MAGNETIC CONDITIONING WITH CAPACITOR DISCHARGE

A-1. PRINCIPLE

A-1.1 A capacitor is charged to a pre-set voltage and then discharged through an inductor in series with a test winding on the core to be conditioned. The capacitor and inductor together with the winding on the core and any other elements in the discharge circuit, for example, relay contacts and wiring, determine the oscillatory discharge current. This current flows through the winding on the core obliterating its magnetic history and subjecting it to a reproducible magnetic disturbance.

A-2. MAIN CHARACTERISTICS

A-2.1 The following data refer to the complete discharge circuit with a short circuit placed across the terminals for the test winding:

a) Time constant, τ	$<0{\cdot}25$ s
b) Frequency of discharge current, f	<150 Hz
c) Number of cycles during time constant period, τf	>4*
d) Peak voltage across the capacitor terminals in maximum setting	$\geqslant 200$ V
e) Highest peak discharge current in maximum setting	$\geqslant 3$ A

The inductance and resistance of the winding on the core shall be such that the characteristics of the discharge circuit remain within the limits specified above.

A-3. SUGGESTED DESIGN

A-3.1 The following components will provide characteristics according to the limits specified in **A-2.1**:

a) Discharge inductor approximately 70 mH, and

b) Discharge capacitor approximately 25μF.

The discharge inductor should not be saturated at the maximum peak discharge current of 3A and the capacitor should be capable of delivering this current. The discharge circuit control relay should have contacts providing low and stable resistance, for example, a mercury wetted contact relay.

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*This corresponds to a ratio of one peak of the discharge current to the next in the same direction of maximum 1·28.

In order to obtain repeatable results, the capacitor should be charged from a closely regulated dc power supply (*see* Fig. 4). The test windings used for magnetic conditioning with this apparatus should be so designed that the inductance of a winding on the core to be conditioned does not exceed 5 mH and its resistance does not exceed 0 5 Ω.

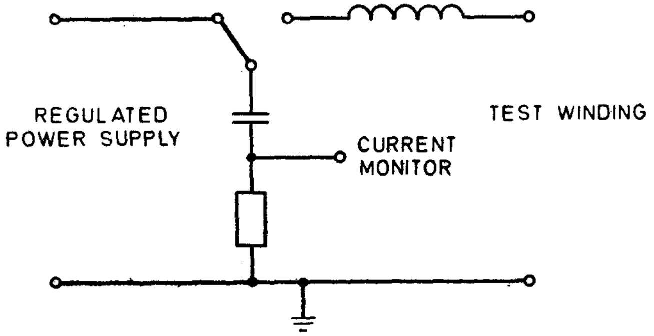

FIG. 4 APPARATUS FOR MAGNETIC CONDITIONING WITH CAPACITOR DISCHARGE

A test terminal should be provided to monitor the discharge current through the winding on the core. The series resistance introduced in the discharge circuit for monitoring should be as low as possible, for example, 0·1 Ω.

The conditioning device may be controlled remotely, for example, by a timing device.

APPENDIX B

(*Clause* 6.3)

POWER AMPLIFIER FOR MAGNETIC CONDITIONING

B-1. PRINCIPLE

B-1.1 A sine-wave generator supplies the input signal to the power amplifier. A suitable gain control circuit is used to shape the amplitude of the amplifier output over a time interval so as to provide a current in the test winding on the core to be conditioned having the desired frequency and with a prescribed peak amplitude variation. Circuit arrangement is shown in Fig. 5.

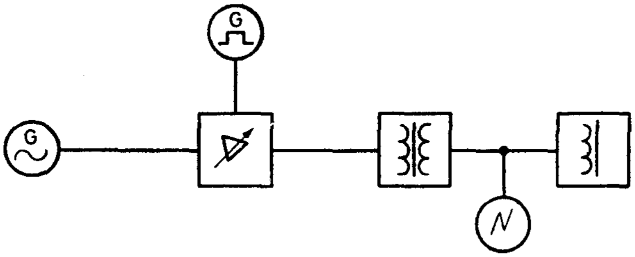

FIG. 5 POWER AMPLIFIER FOR MAGNETIC CONDITIONING

B-2. MAIN CHARACTERISTICS

B-2.1 The following data refer to the amplifier terminated with the nominal load resistance:

a) Frequency of output current, f	<150 Hz
b) Initial output power, P	$\geqslant 20$ W
c) Characteristic of output current pulse	Linear or exponential

B-2.1.1 For linear characteristic:

Number of cycles between maximum and minimum output, η	$\geqslant 50$

B-2.1.2 For exponential characteristic:

a) Time constant, τ	$\leqslant 0{\cdot}25$ s
b) Number of cycles during time constant τ_f	>4*
c) Distortion at 20 W	<3 percent
d) Maximum hum voltage	The combination of these voltages may cause a peak flux density of 0·1 mT in the core to be conditioned
e) Maximum noise voltage	
f) Maximum output voltage at minimum gain	

B-2.2 The power amplifier shall be coupled to the test core in such a way that the core may be driven into saturation and that the required envelope of the current in the test coil is maintained.

B-3. SUGGESTED EQUIPMENT

B-3.0 This clause gives an example of a practical test set-up which will operate within the limits specified in **B-2.1**.

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*This corresponds to a ratio of one peak of the output current to the next in the same direction of maximum 1·28 and is in accordance with Appendix A.

B-3.1 Sine-Wave Generator — The lower limit of the frequency range shall not be higher than 100 Hz and it shall have sufficient output to drive the amplifier to 20 W output. At that value of the generator output, the distortion of the output shall not exceed 1 percent.

The generator shall be suitable for unbalanced operation.

B-3.2 Power Amplifier — The lower 3 dB point of the frequency characteristic shall lie at or below 70 Hz and the higher 3 dB point shall lie at or above 2 000 Hz. When terminated with the nominal load resistance and driven by a sinusoidal input, the distortion of the output at 20 W shall not exceed 2 percent.

The output impedance shall be low (for example, 16 Ω).

B-3.3 Matching Transformer — The power rating shall not be less than 20 VA and the recommended impedance ratios, selectable by a switch, for the case of an amplifier output impedance of 16 Ω are:

16: 1
16: 3
16: 6
16: 10
16: 20
16: 35
16: 60
16: 100

When properly terminated at both sides and with sinusoidal input, the distortion at 20 W output shall not exceed 1 percent.

B-3.4 Gain Control — This shall meet the requirements of **6.3**(a) (1) or (2) (*see also* **B-2**).

The gain-time characteristic of the amplifier may be obtained by mechanical means, such as a potentiometer, or by an electronic circuit. The latter may utilize a voltage pulse, for example, generated by a capacitor discharge, or by a resistor or semiconductor device which will show a change in characteristic from a flash of light or other stimulus.

The gain control may be controlled remotely, for example, by a timing device.

APPENDIX C

(*Clause* 6.3)

APPARATUS FOR MAGNETIC CONDITIONING BASED ON THE ALTERNATING FIELD METHOD

C-1. APPARATUS

C-1.1 The number of terms of the windings, the current through them and the dimensions of the air gap shall be so chosen as to obtain in the air gap a field strength of approximately 25 kA/m. The frequency normally is power frequency.

APPENDIX D

(*Clause* 6.4)

THERMAL METHOD FOR MAGNETIC CONDITIONING

D-1. METHOD

D-1.1 The core to be conditioned shall be introduced into a temperature chamber and heated to a temperature approximately 25°C above the Curie point, at a rate not exceeding 2°C/min. The core shall be kept at this temperature for not less than 30 minutes or more than 50 minutes.

NOTE — When the Curie point is not known, the inductance shall be monitored during the heating period or the Curie point shall be determined by a separate test.

D-1.2 Subsequently, the core shall be allowed to cool down to the measurement temperature in not less than $1\frac{1}{2}$ hours, or more than $2\frac{1}{2}$ hours at a rate not exceeding 5°C/min. It is recommended that during the last 10 minutes before the reference time is reached, the cooling rate shall be controlled between 3°C/min and 5°C/min.

D-1.3 When the core has cooled down, until the measurement temperature is reached, it may be introduced into an insulated constant temperature chamber and be kept there until the measurements are started. During this transfer, care shall be taken to avoid mechanical stresses in the material.

NOTE — Before using this method, it shall be verified that, as a result of the heating cycle, the core material will not show irreversible changes (such as may occur in materials with constricted loop) and the wire insulation and mounting components will not show secondary effects of a significant magnitude.

During the whole procedure, the core shall be protected against magnetic disturbances.

APPENDIX E

(*Clause* 7.2)

GUIDE FOR THE DESIGN OF INDUCTANCE MEASUREMENT COILS FOR NEWLY DEVELOPED TYPES OF CORES

E-1. OBJECT

E-1.1 To give common design principles for inductance measuring coils for newly developed ferrite core types for use in transformers and inductors for telecommunications, which will enable the manufacturers developing these new core types to establish associated inductance measuring coils which will be generally acceptable and which will yield reproducible values of the inductance factor.

NOTE — These principles still leave a certain amount of discretion on part of the designer but it is envisaged that the originator of the core design would propose the dimensions of the test-coil in accordance with this guide and these would be accepted as standard.

E-2. GUIDE FOR THE DESIGN OF INDUCTANCE MEASURING COILS

E-2.1 The coil shall be wound as a mechanically self-supporting winding on a mandrel between flanges. The use of the so-called orthocyclic winding technique is recommended and the wire used shall be in accordance with Type 'B' of IS: 4800 (Part X)-1977*.

NOTE — It may sometimes be desirable to select a particular batch of wire from stock in order to reduce the tolerance on the diameter.

E-2.2 The geometry of the test coil should correspond with that of the coils which are used in the normal production situation of inductors and transformers using this core, that is, its cross section should be similar and take into account the normal flange thickness and clearances appropriate to the particular core design.

E-2.3 The diameter of the mandrel chosen in accordance with **E-2.2** shall have a tolerance of $^{-0}_{+0{\cdot}01}$mm. There is no further tolerance requirement on the inner diameter of the winding, d_{ci}.

E-2.4 The design number of turns shall be about 100 and all layers shall be fully wound to ensure symmetry.

E-2.5 The maximum value of the winding width, follows from the number of turns per layer and the maximum diameter of the wire chosen, and shall be in accordance with **E-2.2**. From the maximum value so calculated, the nominal winding width shall be derived and the tolerance shall not exceed ±0·1 mm.

E-2.6 The maximum value of the outer diameter of the winding, d_{co}, follows from the mandrel diameter, the number of layers, the maximum diameter of the wire chosen and the unavoidable out of roundness which equals 0·14 × the overall wire diameter for an orthocyclic winding.

This maximum value shall not exceed the minimum winding chamber diameter of the core design in question minus 1·1 mm, also, where possible, the outer diameter shall correspond approximately to 80 percent full copper winding (*see* Fig. 6).

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*Specification for enamelled round winding wires: Part X Self-bonding wires.

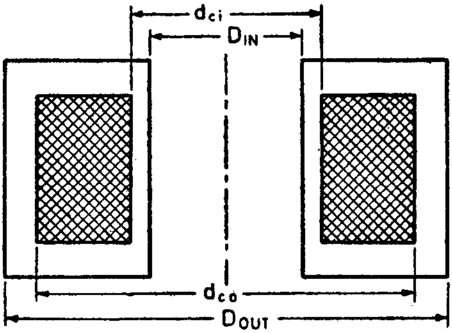

FIG. 6 DIMENSION OF INDUCTANCE MEASUREMENT COIL

$$d_{co} \leqslant D_{out} - 1{\cdot}1 \text{ mm}$$

$$d_{co} \approx D_{in} + 0{\cdot}8\ (D_{out} - D_{in}) = 0{\cdot}8\ D_{out} + 0{\cdot}2\ D_{in}$$

where

d_{co} = outer diameter of copper winding,

D_{out} = minimum inside chamber diameter of core, and

D_{in} = maximum centre limb diameter of core.

From the value so calculated, the rated outer copper diameter shall be derived. The tolerance, neglecting the out of roundness of the coil, shall not exceed:

±0·1 mm for small cores, and

±0·3 mm for the largest cores.

E-3. EXAMPLE OF CALCULATION

E-3.1 Design of the RM 6 Measuring Coil — The following are the dimensions of a coil former:

Mandrel diameter $7{\cdot}3^{+0\ 01}_{-0}$ mm

Permissible winding width 7·1 mm (*Max*)

From the core diameters:

Inside chamber diameter $D_{out} = 12{\cdot}4$ mm (*Min*)

Centre limb diameter $D_{in} = 6{\cdot}4$ mm (*Max*)

The outer diameter of copper winding d_{co} is derived as follows:

Maximum: $12{\cdot}4 - 1{\cdot}1 = 11{\cdot}3$ mm

80 percent full: $0{\cdot}3 \times 12{\cdot}4 + 0{\cdot}2 \times 6{\cdot}4 = 11{\cdot}2$ mm.

The design has now to be completed for various chosen wire diameters and from these results, the most suitable one can be selected. The rest of this example shows the calculation of the most suitable orthocyclic winding:

Wire diameter chosen 0·315 mm; overall diameter 0·357 mm (*Max*).

Number of turns per layer: $7{\cdot}1/0{\cdot}357$ = nearly 20; the appropriate number is then 19 and the actual length for orthocyclic winding $19{\cdot}5 \times 0{\cdot}357$ mm = 6·96 mm (*Max*). The winding width is fixed as $7^{+0}_{-0{\cdot}1}$ mm.

Maximum outer copper diameter d_{co} (including out of roundness) = $7{\cdot}3 + 0{\cdot}357\,[2{\cdot}14 + (n-1)\sqrt{3}\,]$ the number of layers n being 6 in this case.

$d_{co} = 11{\cdot}16$ mm (*Max*); the outer copper diameter is fixed at $11{\cdot}1 + 0{\cdot}1$ mm.

Number of turns: $N = 6 \times 19 - 1 = 113$.

APPENDIX F

(*Clause* 9.7)

METHOD OF EXPRESSING TEMPERATURE DEPENDENCE

F-1. PRINCIPLE

F-1.1 There are several possible parameters that may be used to describe the temperature dependence of the inductance or the permeability. The choice of the parameter for a core is different from that for a material.

For a given parameter three methods of specifying it are distinguished; these represent an increasing order of definition:

a) mean temperature dependence (*see* **F-3.1**),
b) absolute limits of temperature dependence (*see* **F-3.2**), and
c) limits of slope (*see* **F-3.3**).

F-2. PARAMETERS

F-2.1 For a core, the parameter shall be defined as:

$$p = \frac{L_\theta - L_{ref}}{L_{ref}} \text{ or}$$

$$p = \frac{A_{L\theta} - A_{Lref}}{A_{Lref}}$$

where

L_θ ($A_{L\theta}$) = self-inductance (specific inductance) measured at any temperature, and

L_{ref} (A_{Lref}) = self-inductance (specific inductance) measured at the reference temperature θ_{ref}.

The slope of the tangent or chord to the curve giving p as a function of θ represents the temperature coefficient of the core inductance.

For a material, the parameter shall be defined as:

$$p = \frac{\mu_\theta - \mu_{ref}}{\mu_\theta \, \mu_{ref}} = -\left(\frac{1}{\mu_\theta} - \frac{1}{\mu_{ref}}\right)$$

where

μ_θ = relative permeability (for example, initial permeability) measured at any temperature θ; and

μ_{ref} = the corresponding permeability measured at the reference temperature θ_{ref}.

The slope of the tangent or chord to the curve giving p as a function of θ, represents the temperature factor of the material permeability, as defined in **F-6.3**, equation (8).

F-3. METHODS OF EXPRESSION

F-3.1 Mean Temperature Dependence — In this method, the reference temperature θ_{ref} and limits for the value of the parameter at a stated temperature $\theta 1$ are fixed, neglecting the behaviour between these temperatures. This method recognizes current practice and is suitable where the temperature dependence need not be strictly defined.

An upper limit u and a lower limit l are specified for:

$$\frac{p_1}{\theta_1 - \theta_{ref}}$$

where

p_1 is the value of the parameter corresponding to $\theta_1 - \theta_{ref}$.

This specification may be represented graphically by three points as shown in Fig. 7.

NOTE — This specification may be expressed by a nominal value with tolerance, the reference and limit temperature, for example:

a) In the case of material: mean temperature factor $(1 \pm 0{\cdot}5) \times 10^{-6}/°C$ between 25°C and 70°C, and

b) In the case of a core: mean temperature coefficient $(100 \pm 50) \times 10^{-6}/°C$ between 25°C and 70°C.

F-3.2 Absolute Limits of Temperature Dependence — Apart from the limits specified for the mean temperature dependence, in this method specific limits apply for the parameter over the temperature range between the reference and the limit temperatures. This provides a better definition of temperature dependence over a given temperature range.

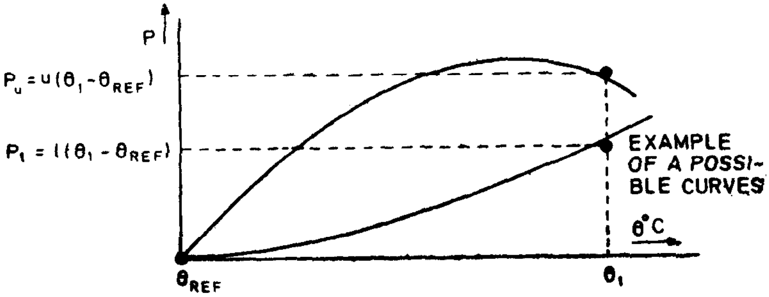

FIG. 7 GRAPHICAL REPRESENTATION OF MEAN TEMPERATURE DEPENDENCE

In addition to the limits of **F-3.1**, namely an upper limit u and a lower limit l for $\frac{p_1}{\theta_1 - \theta_{ref}}$, p shall be linear with θ within a constant tolerance $p_u - p_1$ over the temperature range θ_{ref} to θ_1.

Mathematically this expression is represented by:

$$p = \left(\frac{u+l}{2}\right) (\theta - \theta_{ref}) \pm \left(\frac{u-l}{2}\right) (\theta_1 - \theta_{ref})$$

It may be graphically represented by one point (at the reference temperature) and by a parallelogram as shown in Fig. 8.

NOTE — This specification may be expressed by a nominal value with tolerance over the temperature range, for example:

a) In the case of a material: absolute limits for temperature factor $(1 \pm 0{\cdot}5) \times 10^{-6}$/°C over the temperature range between 25°C and 70°C, and

b) In the case of a core: absolute limits for temperature coefficient $(100 \pm 50) \times 10^{-6}$/°C over the temperature range between 25°C and 70°C.

This nominal value is equal to $\frac{u+l}{2}$ and corresponds to the dotted centre line of the parallelogram in Fig. 8. The tolerance is $\pm \frac{u-l}{2}$.

In some cases, for example, when the temperature range extends to both sides of the reference temperature, asymmetrical tolerances may be used to obtain a smaller tolerance zone. Example: absolute limits for temperature factor within $\left(1{\cdot}2 \begin{smallmatrix}+0{\cdot}3\\-0{\cdot}6\end{smallmatrix}\right) \times 10^{-6}$/°C over the temperature range between 5°C and 70°C. In that case, the nominal value is used as the basis for the construction of the parallelogram which then is asymmetrical with respect to the reference point.

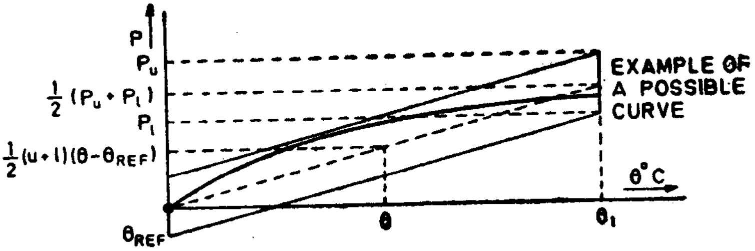

FIG. 8 GRAPHICAL REPRESENTATION OF ABSOLUTE LIMITS OF TEMPERATURE DEPENDENCE

F-3.3 Limits of Slope — In addition to the absolute limits on p as specified in **F-3.2,** it may be required to add limits on the slope of the $p-\theta$ curve measured at any point on the curve between θ_{ref} and θ_1 (for example, to require that the curve shall not change sign). It may be desirable for further shape information to be given, for example, that the curve is concave upwards (or downwards).

F-4. SUB-DIVISION OF TEMPERATURE RANGE

F-4.1 The above rules may also be applied to temperature ranges extending to both sides of the reference temperature. In graphical representation, the first method then results in five points, one at reference temperature and a pair at each of the limit temperatures, each pair being calculated in exactly the same way as indicated in **F-3.1**.

To obtain narrower tolerance limits, the total temperature range may, however, be sub-divided at the reference temperature and separate limits specified for each part. There may even be more sub-divisions and limits specified for each combination of reference temperature and limiting temperature.

For example, a core might be characterized by four parallelograms forming an inner and outer zone as shown in Fig. 9.

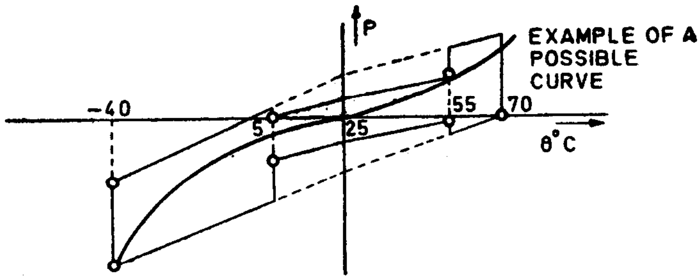

FIG. 9 GRAPHICAL REPRESENTATION OF SUB-DIVISION OF TEMPERATURE RANGE

F-5. STANDARD TEMPERATURES

F-5.1 The preferred reference temperature is 25°C.

F-5.2 Preferred limiting temperatures are:

−40°C, −25°C, +5°C, +55°C, and +70°C.

F-6. EXPLANATION

F-6.1 The choice of the parameter $p = \frac{\mu_\theta - \mu_{\text{ref}}}{\mu_\theta \, \mu_{\text{ref}}} = -\triangle\left(\frac{1}{\mu_r}\right)$, for the expression of the temperature dependence of the material permeability arises from two considerations:

a) This parameter is of a form suitable for expressing compensation of the temperature coefficient of a linear capacitor in a tuned circuit (*see* **F-6.2**); and

b) This parameter, when determined with a normal winding on a core with minimum air gap, permits the theoretically correct calculation of the temperature coefficient, over the same temperature range of a core gapped to give a particular effective permeability (*see* **F-6.3**).

F-6.2 In a tuned circuit, it is required that the product *LC* should remain constant with temperature. Therefore, when *C* varies in a linear manner with temperature, the requirement for the core is that of the inverse of inductance should vary in a linear manner also.

The inverse of the inductance of a coil is proportional to the effective reluctivity of the core (the inverse of effective permeability) and in a well-designed coil this is the only parameter that will vary appreciably with temperature. Hence, the temperature coefficient of reluctivity $\alpha\nu$ is required to be a constant over the temperature range to be considered:

$$\alpha\nu = \frac{\mu_{e.\text{ref}} \triangle (1/\mu_e)}{\triangle \theta} \qquad .. \text{(1)}$$

where $\mu_{e.\text{ref}}$ is the effective permeability of the core at reference temperature.

In a gapped magnetic circuit producing an effective permeability, μ_e, from a relative material permeability μ_r:

$$\frac{1}{\mu_e} = \frac{\frac{1}{\mu_r} + \delta}{1 + \delta} \qquad .. \text{(2)}$$

where δ is the ratio of air gap length to the magnetic path length inside the material, on the basis of the effective cross-sectional area (*see* IS: 7616-1974*).

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*Guide for calculation of the effective parameters of magnetic piece parts.

In most cases, $(1+\delta)$ is very closely equal to 1 so that to a close degree of approximation:

$$\Delta\left(\frac{1}{\mu_e}\right) = \Delta\left(\frac{1}{\mu_r}\right) = -p \qquad \text{.. (3)}$$

so

$$\alpha_\nu = \mu_{e\cdot ref}\frac{\Delta\left(\frac{1}{\mu_r}\right)}{\Delta\theta} = -\mu_{e.ref}.\frac{p}{\Delta\theta} \qquad \text{.. (4)}$$

It follows that when α is required to be independent of temperature, the parameter p should be linear with temperature.

F-6.3 The temperature coefficient of the effective permeability of a core is:

$$\alpha\mu_e = \frac{\Delta\mu_e}{\mu_{e\cdot ref}\,\Delta\theta} \qquad \text{.. (5)}$$

From this and equation (1), it may easily be shown that:

$$\alpha\mu_e = -\frac{\alpha_\nu}{1+\alpha_\nu.\,\Delta\theta} \qquad \text{.. (6)}$$

Combining this with (4) results in:

$$\alpha\mu_e = \frac{p\mu_{e.ref}}{\Delta\theta\;(1-p\mu_{e.ref})} \qquad \text{.. (7)}$$

Which shows that p is also the correct parameter for the calculation of the temperature coefficient of the effective permeability of a core.

When the temperature factor of the material permeability is defined as:

$$\alpha_F = -\frac{\Delta\left(\frac{1}{\mu_r}\right)}{\Delta\theta} = \frac{p}{\Delta\theta} \qquad \text{.. (8)}$$

Equation (7) may also be written as:

$$\alpha\mu_e = \frac{\alpha_F\mu_{e.ref}}{1-\alpha_F\mu_{e.ref}\Delta\theta} \qquad \text{.. (9)}$$

NOTE 1 — When $\frac{\Delta L}{L}$ over the temperature range considered is small (and this is normally the case for tuned circuits), the denominator in the last term of equation (9) approaches (1) and the equation reduces to:

$$\alpha\mu_e = \alpha_F\,\mu_{e\cdot ref} = -\alpha_\nu$$

NOTE 2 — The following definition of the temperature factor of permeability has also been used:

$$\alpha'_F = \frac{\Delta\mu_r}{\mu_{ref}{}^2\,\Delta\theta}$$

Since no accurate formula may be derived for the relation between this factor and the temperature coefficient of either permeability or reluctivity, and approximations are less good than those with the temperature factor defined in question (8) of this appendix, its use should be deprecated.

APPENDIX G

(*Clause* 11.6)

DAMPED OSCILLATION METHOD FOR LOSS MEASUREMENT CALIBRATION

G-1. PRINCIPLE

G-1.1 The inductor to be measured is connected in parallel with a high-quality capacitor such that the resonant frequency of the combination substantially equals the measuring frequency. This circuit is pulse excited and the resulting damped oscillation is observed on a calibrated oscilloscope. The amplitude of the voltage is measured at the start and finish of a known time interval and the quality factor is derived from these measurements.

Only the overall quality factor may normally be measured by this method.

A variety of measuring techniques may be used, one of which is illustrated as an example in Fig. 10 and described below.

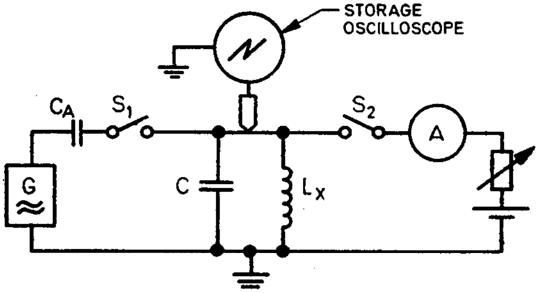


FIG. 10 CIRCUIT ILLUSTRATING A MEASURING TECHNIQUE FOR LOSS MEASUREMENT BY DAMPED OSCILLOSCOPE METHOD

G-2. ACCURACY OF THE METHOD

G-2.1 An inaccuracy of less than 2 percent can be obtained provided the corrections for probe resistance and capacitor loss are relatively small.

G-3. MEASURING CIRCUIT DETAILS

G-3.1 The coupling capacitance C_A shall be very small compared with the resonating capacitance C so that the generator impedance has negligible effect on the resonant circuit. The impedance of the probe shall be very high; otherwise the impedance shall be known and a correction made as described below.

G-3.2 With S_2 open and the oscilloscope operating in the non-storage mode, S_1 is closed and the frequency of the generator is adjusted to the resonant frequency as observed by the maximum amplitude indication on the oscilloscope. The voltage across the inductor should correspond approximately to the specified flux density. If the resonant frequency is not close enough to the specified measuring frequency than C should be adjusted. When the resonant frequency is close enough to the measuring frequency, switch S_1 is opened and, in addition, the generator is switched off.

G-3.3 Switch S_2 is then closed and the direct current is adjusted to a value to the specified flux density, care being taken not to allow excessively large currents to flow through the inductor. The oscilloscope is switched to the storage mode and switch S_2 is opened.

G-3.4 The ensuring damped oscillation is recorded on the oscilloscope. If the trace is not suitable for measurement purpose, the vertical sensitivity and the sweep rate shall be adjusted and the procedure of this paragraph repeated until the trace envelope appears as shown in Fig. 11 (high quality factor) or Fig. 12 (low quality factor).

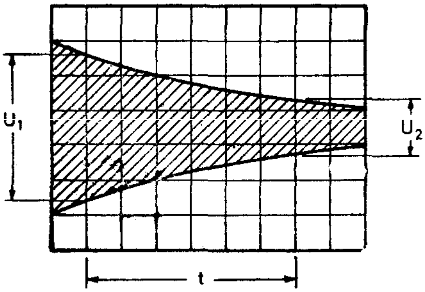


FIG. 11 SWEEP ADJUSTMENT OF OSCILLOSCOPE (FOR MEASUREMENT OF HIGH QUALITY FACTORS)

G-4. CALCULATIONS

G-4.1 The calculations are given below:

High quality factor (Fig. 11): measure voltage U_1 and U_2 (or quantities proportional to them) and the time interval t:

$$Q_1 = \frac{\omega t}{2 ln \dfrac{U_1}{U_2}}$$

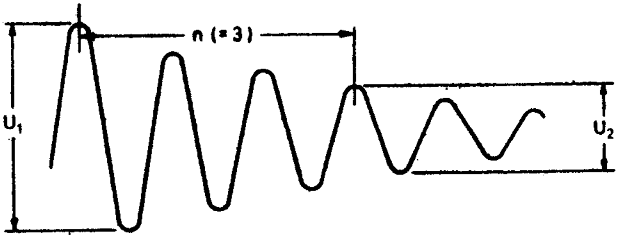


FIG. 12 SWEEP ADJUSTMENT OF OSCILLOSCOPE (FOR MEASUREMENT OF LOWER QUALITY FACTORS)

Low quality factor (Fig. 12) measure voltages U_1 and U_2 (or quantities proportional to them) and the number of cycles n:

$$Q_1 = \frac{\pi n}{ln \frac{U_1}{U_2}}$$

where Q_1 is the uncorrected quality factor of resonant circuit.

If the shunt resistance of the probe is not sufficiently high to be neglected, correction is given by:

$$Q_{LC} = \frac{RQ_1}{R-Q_1\omega L}$$

where

Q_{LC} = corrected quality factor of resonant circuit,
R = parallel resistance of probe, and
L = parallel inductance of inductor under test.

Correction for capacitor loss:

$$Q_L = \frac{Q_{LC}\ Q_C}{Q_C-Q_{LC}}$$

where

Q_{LC} = corrected quality factor of resonant circuit, and
Q_C = quality factor of capacitor.

G-5. ALTERNATIVE MEASURING TECHNIQUES

G-5.1 Instead of using a storage oscilloscope (*see* Fig. 10), a triggered oscilloscope and camera may be used.

G-5.2 A normal repetitive time base oscilloscope may be used. In this case, the exciting circuit shall pulse the resonant circuit and also synchronize the time base. Care shall then be taken that the exciting circuit does not load the resonant circuit; low capacitance coupling *via* an antenna placed in the proximity of the resonant circuit can be used. It is also important to ensure a stable repetition of the trace.

G-5.3 Another technique is to replace the oscilloscope by a voltage sensing circuit set to count and display the number of cycles between preset voltages U_1 and U_2. If the ratio of U_1 and U_2 is made equal to 23·1 the indicated number of cycles equals Q_1.

APPENDIX H

(*Clause* 11.6)

TRANSMISSION METHOD FOR LOSS MEASUREMENT CALIBRATION

H-1. PRINCIPLE

H-1.1 The inductor to be measured is combined with a high quality capacitor to form an *LC* circuit resonating at the measuring frequency. The effective resistance at resonance is measured by determining the attenuation of a transmission path containing the resonant circuit. The quality factor is calculated from this resistance and the reactance of the inductor measured under identical conditions, taking into account the losses due to circuit components.

NOTE — The parallel connection of inductor and capacitor may also be used if desired. If the parallel connection of inductor and capacitor is used, the characteristics of the components in the circuit should be adopted.

H-2. CIRCUIT

H-2.1 The circuit is shown in Fig. 13. The generator *G* is variable in frequency and voltage. The resistance of the two resistors R_1 is equal to the characteristic resistance of the attenuator. Resistance R_2 is approximately twice the effective series resistance (R_X) of the resonant circuit (which should be estimated in advance), or 5Ω whichever is the greater.

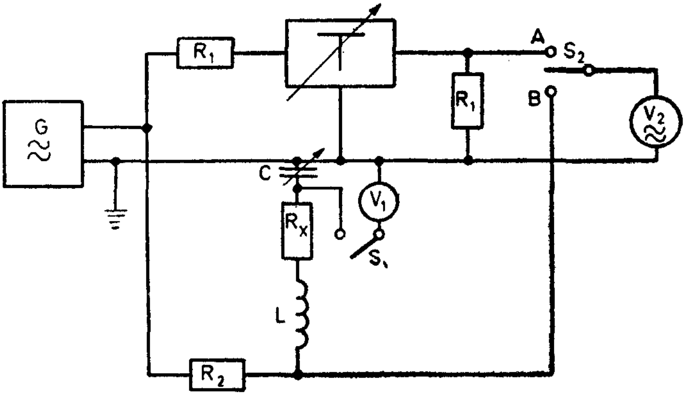


FIG. 13 CIRCUIT ILLUSTRATING A MEASURING TECHNIQUE FOR LOSS MEASUREMENT BY TRANSMISSION METHOD

The attenuator shall be able to resolve 0·1 dB with sufficient accuracy. The accuracy of this method mainly depends on the accuracy of the attenuator.

Voltmeter V_1 is a high-impedance ac voltmeter.

Voltmeter V_2 is a tuned detector having an input impedance very much greater than R_1 and R_2.

H-3. MEASURING PROCEDURE

H-3.1 With switch S_1 closed, the frequency of the generator is adjusted to the resonant frequency of the *LC* circuit as indicated by maximum deflection of V_1. If the frequency is then not within the specified limits, the capacitance *C* shall be readjusted.

The voltage of the generator shall be so adjusted that the requirements of **11.4** are met. The frequency is then readjusted to resonance if necessary and switch S_1 is opened.

With switch S_2 in position *B*, the tuning of detector V_2 is adjusted for maximum deflection. The capacitor *C* is then returned for minimum deflection of V_2 (to compensate the opening of S_1). The attenuator is adjusted until the detector indication is the same for either position of switch S_2. The attenuator setting α (in dB) is noted.

H-4. CALCULATIONS

H-4.1 The calculations are given below:

$$Q_{LC} = \frac{\omega L}{R_x} = \frac{\omega L}{R_2}\left(2 \cdot 10^{\alpha/20} - 1\right)$$

where

Q_{LC} = quality factor of *LC* circuit;

L = series inductance of inductor under test, measured according to **7.3**; and

R_x = equivalent series resistance of *LC* circuit;

Corrections for capacitor loss and for self-capacitance of the inductor:

$$Q_L = \frac{Q_{LC}\ Q_C}{Q_C - Q_{LC}}\left(1 + \frac{2C_s}{C}\right)$$

where

Q_L = corrected quality factor of the inductor under test,

Q_C = quality factor of capacitor,

C_s = self-capacitance of the inductor under test, and

C = capacitance of the resonating capacitor.

APPENDIX J

(*Clause* 12.5)

EXAMPLE OF A TEST SET-UP FOR MEASURING THIRD HARMONIC DISTORTION

J-1. TEST SET-UP (LOW IMPEDANCE METHOD)

J-1.1 The test set-up shown in Fig. 14 is an example of the circuit for measuring third harmonic distortion by low impedance method. The details of the Circuit are given below:

G = adjustable voltage source (oscillator) of given fundamental frequency f_1,

LP = low pass filter with low insertion loss at fundamental frequency. The input impedance shall preferably be matched to the oscillator. The output impedance at third harmonic frequency shall be resistive and of such value R_s that:

$$R + R_s < 0{\cdot}3\ \omega_1 L_x$$

Requirement for the combination of G and LP:

The third harmonic at the output of LP shall be 120 dB below the fundamental.

V_1 = voltmeter for fundamental (or total) voltage.

R = measuring resistor of known value.

V_3 = voltmeter for third harmonic voltage. When it is not a selective voltmeter (for example, a wave analyser), it shall be preceded by.

BP = band-pass filter with low insertion loss at the third harmonic frequency. The attenuation at the fundamental frequency shall be at least 120 dB. The attenuation, in combination with the total circuit, for the fifth and higher order harmonic frequencies together shall be at least 120 dB.

The input impedance at third harmonic frequency shall be much larger than R.

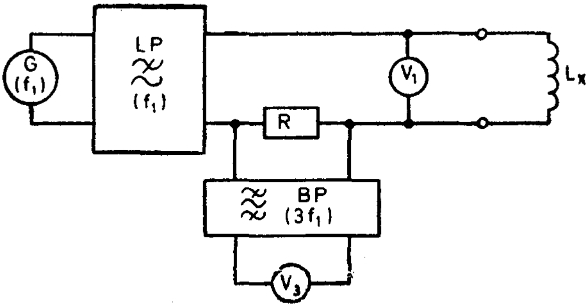


FIG. 14 EXAMPLE OF A TEST SET-UP FOR MEASURING THIRD HARMONIC DISTORTION BY LOW IMPEDANCE METHOD

APPENDIX K

(*Clause* 15.1)

INFLUENCE OF A STATIC MAGNETIC FIELD

K-1. OBJECT

K-1.1 The object of this method is to provide a method for evaluating the change in permeability caused by a change in static magnetization.

K-2. PRINCIPLE OF THE MEASUREMENT

K-2.1 A core shall be subjected to magnetic conditioning and then the inductance corresponding to the reversible permeability is measured for various value of the static field strength, starting at zero applied static field strength.

K-3. SPECIMENS

K-3.1 Cores taken from current production, or cores especially provided for the purpose of material measurements.

NOTE — There is no simple relation between the results of measurements made on cores of the same size with different air gaps.

K-4. MEASURING COIL

K-4.1 All measuring coils shall be suitable for measurement of inductance in accordance with **7.4**, the wire shall be such that during measurement with the maximum direct current required, the inductance change due to change of temperature is negligible. In the case of coils with two windings, these shall have the maximum coupling obtainable; preferably they shall be wound in parallel, with wire of the same diameter.

NOTE — For measurement on gapped cores, it is recommended that the coils should employ as many turns as is consistent with available space and current capacity.

K-5. MEASURING PROCEDURE

K-5.1 The core is assembled with the measuring coil in accordance with **4.3.** In the case of toroidal winding, the turns shall be evenly distributed along the circumference.

K-5.2 The core shall be subjected to magnetic conditioning in accordance with **6.**

K-5.3 Fifteen minutes after conditioning, the inductance shall be measured in accordance with **7.4**. *During measurement, the peak value of the alternating* flux density in any core part shall not exceed 0·25 mT. The frequency of the measuring current shall be stated.

K-5.4 The direct current is then subsequently adjusted to the specified values, starting with the lowest one, up to the maximum specified value. 3 minutes ± 15 seconds after each current adjustment, the inductance shall again be measured in accordance with **K-5.3.**

NOTE 1 — Adequate methods for the inductance measurement in presence of a static field are given in the **K-6.**

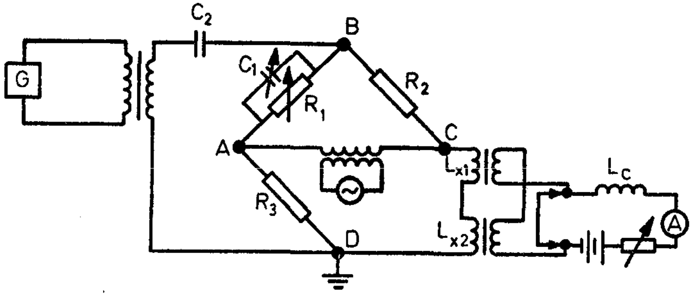
NOTE 2 — Care shall be taken to adjust the direct current slowly to avoid overshoot of the static magnetic field.

NOTE 3 — When a maximum value only is specified, it is recommended that some intermediate steps be introduced.

K-6. SUGGESTED MEASUREMENT SET-UPS

K-6.0 The measurement set-ups are given in **K-6.1** and **K-6.2.**

K-6.1 Maxwell — Type Inductance Bridge for Superimposed Direct Current



A, B, C, D = Bridge junctions
C_1 = Measuring capacitance
C_2 = Blocking capacitance
R_1, R_2, R_3 = Bridge resistors
L_{x1} and L_{x2} = Unknown inductors. These are assumed to be equal, consisting of equal number of turns wound on identical cores
L_c = Inductance of the blocking choke

FIG. 15 MAXWELL TYPE INDUCTANCE BRIDGE

NOTE 1 — This circuit is suitable for frequencies up to 20 kHz.

NOTE 2 — Any bridge configuration may be used provided corner *D* is earthed.

NOTE 3 — The choke L_c should have a low dc resistance and its impedance at the measuring frequency shall for all relevant values of direct current, be greater than the resulting secondary impedance of L_{x1} and L_{x2} and compatible with the required accuracy.

NOTE 4 — An alternative version of the branch *CD* using a single unknown inductor with a single winding test coil is given below:

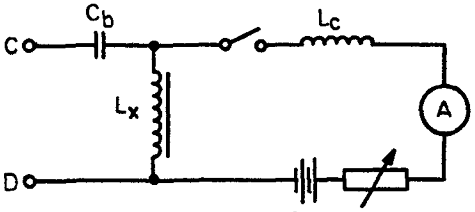


FIG. 16 ALTERNATIVE VERSION OF BRANCH *CD* (*see* FIG. 15)

Where C_b is a blocking capacitor, the impedance of which at the measuring frequency is much smaller, and L_c is a blocking choke the impedance of which is much greater than that of L_x and compatible with the required accuracy.

The blocking capacitor may be omitted when two windings are used, one being the test winding L_x and the other providing the static magnetic field.

K-6.2 Circuit for the Measurement of very Small Variations of Inductors as a Function of Superimposed Direct Current

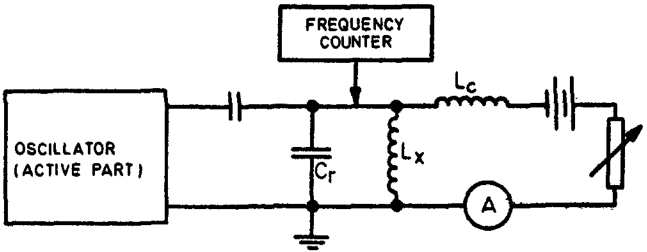


FIG. 17 CIRCUIT FOR MEASUREMENT OF VERY SMALL VARIATIONS OF INDUCTORS

NOTE 1 — L_x and C_r are the frequency determining elements of the oscillator.

NOTE 2 — The blocking impedance shall have low dc resistance and its impedance at the measuring frequency shall for all values of direct currents be much greater than the impedance of L_x and compatible with the accuracy to be obtained.

NOTE 3 — $\frac{\Delta L}{L} \approx 2\frac{\Delta F}{F}$ if $\frac{\Delta F}{F} < 5$ percent

NOTE 4 — $\frac{F_2}{F_1} = \frac{L_1}{L_2}$

NOTE 5 — The circuit is recommended for use up to 200 kHz.

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

Quantity	*Unit*	*Symbol*
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Quantity	*Unit*	*Symbol*	*Definition*
Force	newton	N	1 N = 1 kg.m/s^2
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2

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